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## Energy efficient refurbishment of old listed dwellings: The case of Victorian housing stock

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### Abstract

Architects must contribute to climate change mitigation by designing structures in a way that respects natural, climatic, cultural, social and economic conditions of the local area. Such designs must take advantage of renewable energy resources, such as those derived from sun, wind, earth, and water, as well as locally produced materials. While making buildings more sustainable over time, we need to respect cultural heritage as expressed in the past, the present and the future. Architecture must also ensure thermal comfort and a healthy indoor environment throughout the year, while diminishing conventional fuels consumption on the basis of a bioclimatic, energy efficient approach. Buildings in use or in the course of erection account for over 50% of total greenhouse gas emissions. Consequently, upgrading old inefficient buildings to meet principles of bioclimatic design is an effective way to reduce energy use in industrialized countries. (Smith, 2005) However, refurbishment schemes should include both environmental design and conservation of architectural, historical and social values of old existing stock.

This paper consists of two parts. First, there is a review of the objectives, targets and studies with regards to the old, existing UK housing stock. This section highlights the principles and advantages of bioclimatic design and energy efficient improvements to the fabric and services of listed buildings. The second part contains an evaluation of performance of the recently refurbished Victorian House at 17 St. Augustine's Road in London. Critical assessment of its current performance has been carried out according to winter and summer on-site measurements, simulations and calculations in TAS and SAP softwares. This study will focus more on winter performance and annual heating fuel demands. Occupant behaviour and its impact on the Low Energy Victorian House's (LEVH) performance has also been investigated through a questionnaire survey, while the cost of refurbishment is evaluated in terms of positive effectiveness to annual savings.

### Author's Note

Climate change is by far one of the greatest environmental, social and economic threats our planet faces and is rapidly becoming one of the most serious problems facing human society in the future. Construction activities account for a significant amount of world energy consumption. The impact of climate change on the economy, society and the environment calls for a rapid, fundamental reconsideration of our life style patterns. Now that climate change is an urgent problem requiring immediate action, existing buildings should adapt to bioclimatic design through energy efficient refurbishment in order to improve their

environmental performance and reduce the amount of energy they consume (DTI, 2003). Refurbishment of old dwellings could contribute up to 60% reduction of UK carbon emissions by 2050 (Bows et al, 2006). According to the technical paper of sustainable Development Commission: “Existing properties may be upgraded at acceptable costs to high environmental standards, and that repairing a typical Victorian house is significantly cheaper than replacing it with a new one.” (SDC, 2005) The main objectives of this research are:

- (a) Exploring the contribution of old existing dwellings to climate change.
- (b) Investigating the environmental performance of old existing UK housing in terms of winter and summer internal conditions, heating demands, fuel consumption, and potential of energy conservation if adequate refurbishment schemes take place.
- (c) Presenting the benefits and drawbacks of energy efficient refurbishment strategies, while accounting for conservation of architectural value of listed housing stock.
- (d) Considering the occupants’ attitudes on climate change, behaviour in operating their household, and the impacts of their attitude on energy consumption and carbon emissions of their dwelling.
- (e) Evaluating cost effectiveness and practicality of refurbishment scenarios.

**Keywords:** Energy Efficient Refurbishment; UK existing housing stock; Sustainability; Conservation; Low Energy Victorian House.

## 1. The case of old Victorian housing stock

### 1.1 Introduction

The UK Climate Impacts Programme<sup>27</sup> and the IPCC Fourth Assessment Report<sup>14</sup> agree that warming of the global climate system is indisputable and that greenhouse gas emissions are due to human activity since the mid-20th century.<sup>15</sup>

Buildings are responsible for 40% to 50% of the national primary energy consumption in the UK. Half of which is used in domestic buildings to satisfy needs for lighting, heating and cooling.<sup>19</sup> According to the Sustainable Development Commission survey in 2005, most of the houses that are going to be accommodated in the UK over the next 50 years already exist. Most of them are energy inefficient (Figure 1). Domestic buildings in the UK are responsible for almost 21% of UK greenhouse gas emissions, 50% of water wastage, and 8% of waste generation, 24% of which are construction and demolition wastes.<sup>25</sup>

End-Use Sector Shares of Total Consumption, 2007

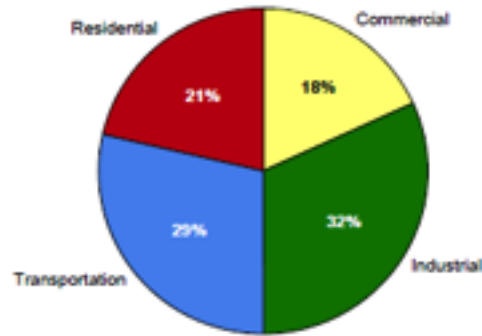


Figure 1: End-use sector shares of total Consumption, 2007. (Source: Annual Energy Review 2007)

Space heating carbon emissions have risen by 12%, reaching 53% of total housing carbon emissions from 1990 to 2003.<sup>3</sup> Today, climate change is receiving unprecedented attention. The Stern Review<sup>13</sup> has explored the economics of climate change. In June 2006, new targets were launched for sustainable operations on the government estate. A new target for the government office estate is to cut carbon emissions from UK housing 15% by 2012, using renewable energy and offsetting the remaining balance of emissions.<sup>1</sup>

The government has started encouraging owners, designers, builders and housing associations to use energy ratings to assess the environmental performance of dwellings and make decisions on sufficient energy efficient refurbishment options.<sup>25</sup> SAP (Standard Assessment Procedure) rating is often used to estimate energy performance and CO<sub>2</sub> emissions of dwellings, taking into account space and water heating.

Improvements to existing dwellings must be done in a bioclimatic and sustainable manner in order to reduce carbon dioxide emissions in the housing sector, encourage a sense of well-being,<sup>16</sup> adapt old existing stock to the modern world's demand for climate change mitigation,<sup>10</sup> and prepare residents for present and future climatic conditions. Thus, refurbishment strategies such as insulation, air tightness, ventilation, and heating and cooling strategies should be interdependent.<sup>9</sup>

Meanwhile, any changes that aim at limiting harmful carbon emissions of listed buildings should be conducted with respect to their historic value.<sup>5,6</sup> Victorian dwellings represent the most popular traditional dwelling type in the UK, constituting a high proportion of habitable dwellings. Most of them are subject to listing due to their aesthetic, social, and historic value. Thus, CO<sub>2</sub> reduction in the housing sector requires reconditioning of listed dwellings, which must be preserved in their original character.

## 1.2 The UK Victorian Dwellings

Between 1801 and 1911 there was rapid increase in the population of England, resulting in an increase of building activity in the UK between 1830 and 1900.<sup>23</sup> The tax-free materials during 1840s and 1850s brought down costs and new construction methods such as polychromic woodwork (usual to Victorian dwellings) became affordable.

The majority of Victorian houses were built on shallow foundations with load bearing walls. Sometimes suspended timber was used for the construction of upper floors, while the ground floor was made of either solid construction or wooden boards above a ventilated sub-floor area. Walls of Victorian dwellings were usually made of solid brickwork of various widths (100mm - 330mm), the pattern of which varies according to the construction system and style of each Victorian house.<sup>22</sup> The Victorian roofs were constructed on site with wooden rafters and various types of covering materials, such as slates. Cast iron gutters and down pipes were incorporated as part of the drainage system. The type of windows used in Victorian houses is known as a “double – hung sash window.” These windows were timber framed and usually consisted of incorporated internal timber shutters. Finally, in most Victorian dwellings both fireplaces and gas stoves were used for heating, while gas lighting was widely used in Victorian times.<sup>23</sup>

## 1.3 The environmental performance

Victorian Houses often perform very well during cold winters and hot summers due to efficient environmental behavior of significant construction elements:<sup>30</sup>

- High thermal mass solid brick walls provide 'inertia' against sharp outside temperature fluctuations. The thermal mass helps internal space maintain a more stable temperature, avoiding sharp changes to the indoor environment from changing external conditions.
- The orientation and size of double hung sash windows control the amount of sunlight coming in, heat gains or losses, and ventilation rates.
- High ceilings further assist the air movement in the internal space, contributing to adequate ventilation rates and indoor air quality.
- When semi-detached, dwellings often are more energy efficient than detached ones, due to smaller exposed surface area (Figure 2).



Figure 2: Victorian semidetached dwellings at 17 & 19 St. Augustine's Road, London. Here it is obvious the solid brickwork construction of walls, the sash windows with internal shutters and the large height of floors. (Source: Personal Archive)

## 2. The process of refurbishment

### 2.1 Energy efficient refurbishment options

It is possible to improve the fabric of traditional buildings by adding insulation to external walls internally or externally.<sup>5,6</sup> However, internal insulation is suggested so as to maintain the appearance of external walls. In order to avoid thermal bridging, insulation in the corners and around window frames or reveals, as well as at spots around eaves must be applied after careful consideration and planning.<sup>4</sup>

Available solutions for improving thermal performance of roofs vary depending on the type of roof (pitched or flat, with or without roof spaces).<sup>4</sup> Flat roofs can be insulated either by a warm deck, where the insulation layer lies above it, or by an inverted roof system technique, where the insulation layer is installed underneath. In pitched roofs, insulation can be applied at the ceiling level, between and above joints, between and above rafter levels, or between and under rafter levels<sup>12</sup> (Figure 3).

Floor insulation can result in almost 60% reduction in heat losses, as it minimizes heat exchange between ground and internal space as well as between heated and unheated floors of a dwelling.<sup>11</sup> In solid floors, insulation can either be applied above slab, helping the room to warm up more quickly when the heating unit is on, or below slab, which reduces the possibility of overheating. This method is preferred in warm, south-facing rooms where the slab on top absorbs heat during the day (Figure 4).

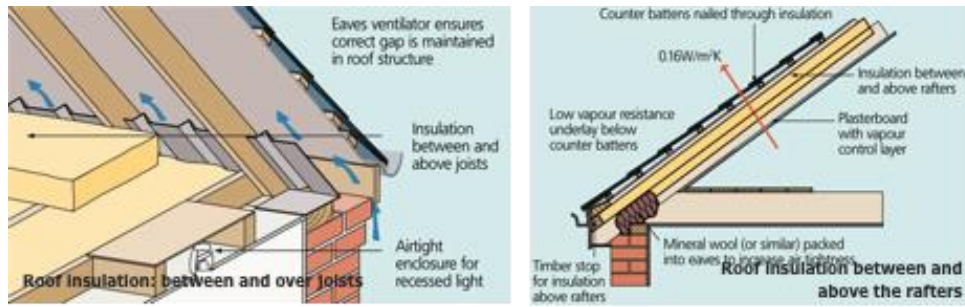


Figure 3: Insulation options for pitched roofs, Left: Roof insulation between and over joists, Right: Roof insulation between and above rafters.<sup>12</sup>

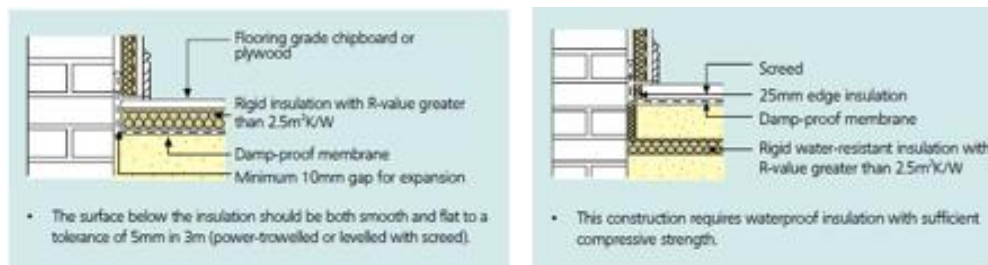


Figure 4: Solid ground floor insulation methods, Left: ground-bearing slab with insulation above slab, Right: -bearing slab with insulation below slab.<sup>12</sup>

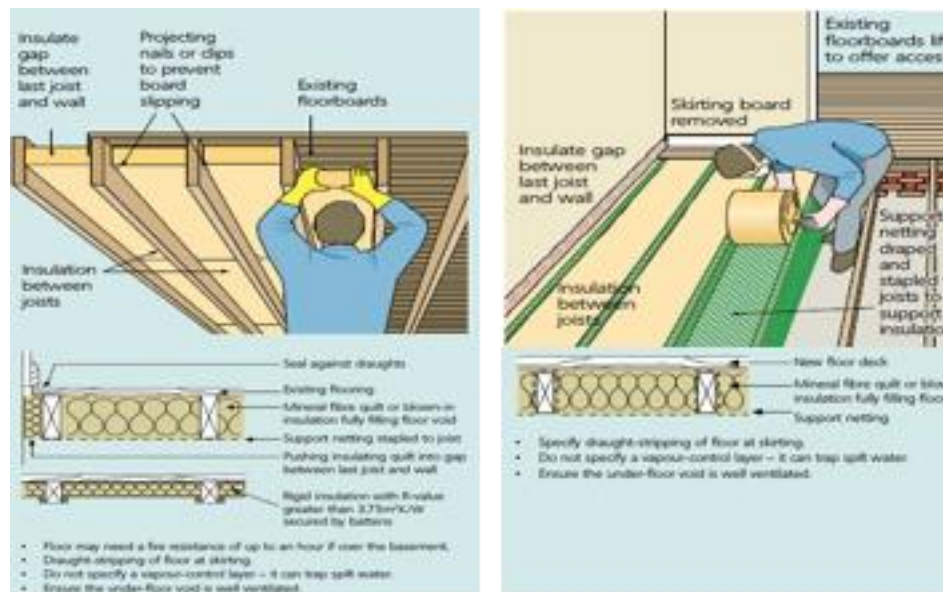


Figure 5: Insulation methods for suspended timber ground floors, Left: access from below, Right: access from above.<sup>12</sup>

In suspended timber ground floors, insulation should completely fill the space between joists and be as thick as the full depth of joist. If there is access, (e.g. in case of a cellar or basement), insulation can easily be installed from below. Where there is no access from below, floorboards have to be removed in order to apply the insulation material between floor joints<sup>12</sup> (Figure 5).

Membranes, expanding foam, and mastic should always be used as additional elements to floor insulation to minimize draft risk around radiator pipes and between floorboards, or between heated and unheated spaces. Draft stripping is also recommended for badly fitting windows and doors. Secondary glazing is suggested when the existing character of dwelling needs to be maintained.<sup>4</sup> Finally, maintenance of existing external shutters should be encouraged to reduce sunlight heat gains during summer and contribute to control of infiltration during winter (Figure 6).

In older times, buildings were ventilated by the loose fitting openings and open fires which provided exhaust ventilation.<sup>4</sup> (Figure 7). Thus, draft proofing and air tightness should be applied after careful consideration, ensuring that ventilation rates in old buildings will not be excessively reduced, putting structural elements in risk of condensation and mold growth, which can cause deterioration of fabric or have impacts on the occupants' health.

As a solution, extracts should be installed in kitchens, bathrooms and laundries, spaces where large amounts of water vapour are produced, while ventilation of roof and floor voids should be ensured.<sup>5,6</sup>

Also, energy consumption of an old dwelling could easily be reduced by:<sup>12</sup>

- Installing a more fuel-efficient boiler.<sup>4</sup>
- Maintaining and servicing heating appliances annually by a licensed technician.
- Installing thermostats to control heating levels, such as thermostatic radiator valves and boiler timers thereby avoiding over-heating by using thermostats to control room temperature.
- Insulating pipe work and hot-water cylinders, to increase the efficiency of the heating and hot water system.
- Fitting photocells or timers to external lights to prevent electricity waste.
- Changing incandescent lamps to energy-efficient versions.

Finally, further reductions in demand for energy can be achieved by adaptation of renewable technologies in traditional dwellings. In the case of listed buildings, planning permission from the conservation office of the local authority is required when installing micro generation equipment attached either to buildings or its cartilage. This ensures that equipment is not visible from important vantage points, does not damage historic fabric, or cause loss of special interest.<sup>7</sup>





Figure 6: Left: secondary glazing; Middle: draft proofing strip inserted to a routed channel of bottom rail of a top sash; Right: external shutters.<sup>4</sup>

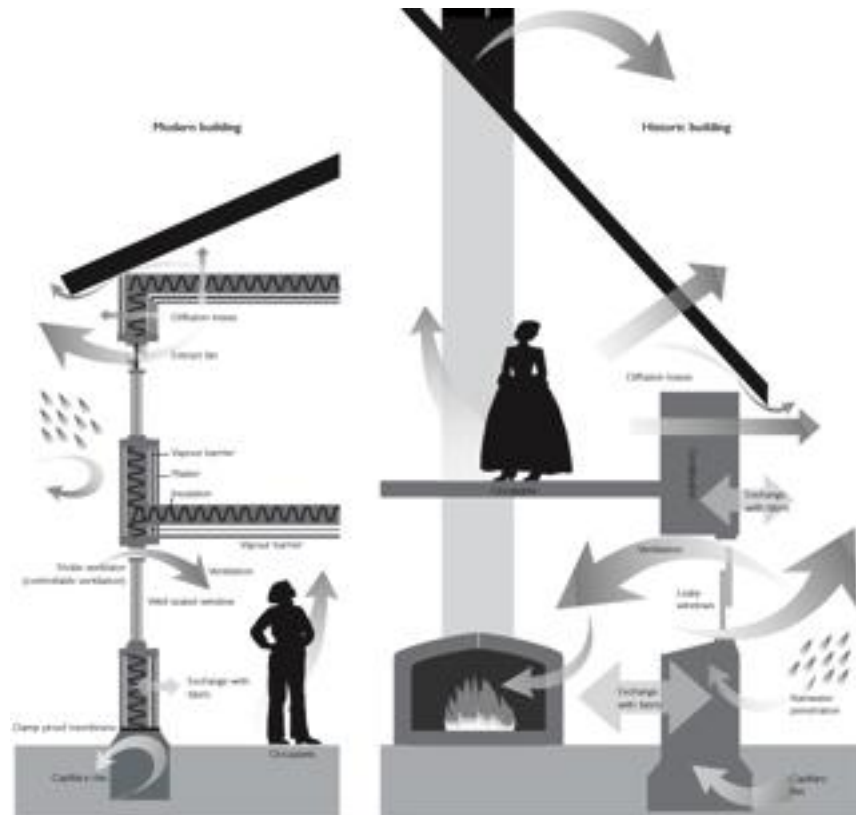


Figure 7: Diagram showing typical differences between the movement of moisture in modern (left) and historic (right) buildings.<sup>4</sup>



Figure 8: The Low Energy Victorian House at 17 St. Augustine's Road, Front View. (Source: Personal Archive)



## 2.2 The 17 St. Augustine's Road refurbished Victorian House

The renovated Victorian House at 17 St. Augustine's Road (Figure 8) stands as a very good example of efficient refurbishment of English housing. It is offered for an investigation into the effectiveness of low-energy refurbishment techniques applied on typical UK Victorian dwellings, regarding the impacts on internal conditions during both winter and summer period. Built in 1850, it is a large Victorian semi-detached dwelling, with a floor area of 250m<sup>2</sup>, situated in Camden, London.

The four-story house had fallen into a state of disrepair. Its poor solid wall construction led to its classification in the "problematic" category of the UK housing stock that contains so-called, "hard to treat homes," that are difficult to refurbish using energy efficient techniques.<sup>3</sup> Recently, the house was refurbished by the Camden Council through the "Low Energy Victorian House (LEVH) Project." This project aims at reducing annual CO<sub>2</sub> emissions of LEVHs by 70% - 90% through environmental design and adaptation of efficient services, while preserving some of the dwelling's most important heritage features, i.e. the traditional external brickwork view.<sup>2</sup> After its refurbishment in 2008, the house was converted into a six-bedroom dwelling and is used for social housing.

The UK government, Camden Council, and firms specializing in eco-friendly construction sponsored the refurbishment. Energy Centre for Sustainable Communities also provided financial support to the project. Research and dissemination of the monitored results and analysis conducted by the Bartlett Faculty of the Built Environment (UCL) was funded by the UrbanBuzz. Insulation was applied to walls internally in order to preserve the traditional facades. The existing solid brick walls were covered by phenolic insulated plasterboards after some essential repairs on the existing brickwork had taken place. All external walls were dry-lined with fixed on battens Kingspan K18 insulated plasterboards, also known as "phenolic insulation," ( $\lambda = 0,21 \text{ W/m}^\circ \text{ C}$ ,  $U - \text{Value} = 0,20 \text{ W/m}^2 \text{ }^\circ \text{ C}$ ) of different thicknesses, varying from 45mm to 90mm depending on the location. Plywood was applied over insulation boards, where heavy fixtures and fittings were placed (Figure 9).

The pitched roof was insulated with 180mm of Kingspan K7<sup>17</sup> ( $\lambda = 0,021 \text{ W/mC}$ ,  $U - \text{Value} = 0,15 \text{ W/m}^2 \text{ }^\circ \text{ C}$ ) between and above the rafters and a breathable membrane was added between the layers and over the top to ensure that the roof would be airtight. Tape was used to seal any gaps between insulation boards and the membrane (Figure 10).

Also, insulation boards (Kingspan K3 with  $\lambda = 0,021 \text{ W/m}^\circ \text{ C}$ ,  $U - \text{Value} = 0,18 \text{ W/m}^2 \text{ }^\circ \text{ C}$ ) have been added over the solid concrete basement floor, which was later covered with a fine screed, while insulation upstands were applied around the edges in order to prevent thermal bridging (Figure 11).



Figure 9: Left: internal view of the original walls; Middle: insulation panel, carried by workers; Right: cut detail of internal insulation fixed to external walls.<sup>18</sup>



Figure 10: Left: finished roof insulation; Middle: applying the Nilvent membrane above the insulation on the roof (Source: Ridley et al, 2007); Right: internal view of the insulation and the sealed junctions on the roof (Source: Personal Archive)



Figure 11: Kingspan Kooltherm K318 insulation boards on the basement floor of LEVH.<sup>21</sup>

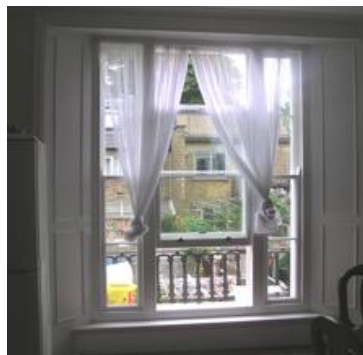


Figure 12: Internal view of double glazed argon filled sash window with angular reveals (Source: Personal Archive)

The original single glazed windows were replaced by new double glazed argon filled sash windows with a wooden frame ( $U - \text{Value} = 1,5 \text{ W/m}^2\text{°C}$ ). Some of the windows have angled reveals which include insulation boards fixed to the wall junction with the window frame to prevent thermal bridging and timber cladding applied over the top for decoration (Figure 5.11).

Finally, any other junctions or gaps were sealed by flexible mastic or expanding foam, aiming to improve air tightness.<sup>21</sup> Initial porosity for 17 St. Augustine's Road was  $30\text{m}^3/\text{m}^2/\text{hr}$ . Now it is reduced to the  $7\text{m}^3/\text{m}^2/\text{hr}$  meeting new build standards.<sup>28</sup>

To improve the efficiency of the LEVH's services, a new oil-condensing model has replaced the old gas boiler. Additionally, new wall-attached heating plants replaced old models and a thermostat was installed to control the thermal conditions in the house. Moreover,  $6\text{m}^2$  of hot water solar thermal and  $3.5 \text{ kWp}$  of solar Photovoltaic Panels have been integrated on the roof in order to contribute to electricity and hot water demands of the house, respectively. The old incandescent light bulbs have been replaced by newer low energy ones.

The LEVH is being monitored and recorded in order to gather data on how such low energy houses perform in terms of energy consumption and occupant comfort (Figure 13).

A special system automatically records the electricity being generated by the PV system, while heat meters consisting of a flow meter, and temperature sensors on the flow and return pipes have been installed on the Solar Hot Water system to record the performance and energy used by the central heating system (Figure 15).<sup>18</sup>

## 2.3 Assessment of LEVH's Environment Performance

After refurbishment, a co-heating test was carried out at the LEVH, in order to measure the heat loss coefficient of the refurbished property. The property was found to have a heat loss of approximately  $280\text{W/K}$ , which met design target. The air permeability was measured by a fan pressurization test and had been successfully reduced from  $30 \text{ m}^3/\text{h}/\text{m}^2$  before refurbishment to be  $6.5 \text{ m}^3/\text{h}/\text{m}^2$ .

Gas consumption in the house was recorded since tenants occupied the house at the end of December 2008.

Measured annual gas consumption of LEVH was  $24,000 \text{ kWh}$  while the annual electricity consumption of LEVH was  $9,000 \text{ kWh}$ . This figure includes any gas used for cooking. The average measured winter internal temperature was  $21.5 \text{ °C}$ . Therefore, tenants are choosing to maintain slightly warmer temperatures, to "take back some increased comfort" at the expense of higher fuel bills.



Figure 13: Left: data logger placed in the basement utility room; Right: sensors measuring the levels of humidity behind the internal insulation boards on walls.



Figure 14: Left: PV meter; Middle: flow meter on solar hot water return and temperature sensor on the solar hot water system; Right: system measuring the energy used by the central heating system.

Assuming a carbon dioxide emission factor of 0.194 kg/kWh for gas and 0.42 kg/kWh for electricity, the approximate CO<sub>2</sub> emissions are contained in Figure 15. The measured annual electricity generation of the PV system was 3000 kWh. The PV system offset 33% of the electricity consumption of the dwelling. In its unrefurbished state the house would have required an annual gas consumption of 75,000 kWh, and electricity consumption of 9000 kWh, as predicted by Parametric SAP. Thus, if savings from the PVs are considered, total gas consumption was reduced by an estimated 68%. Similarly, overall carbon dioxide emissions from gas and electricity use was reduced by an estimated 60%.

Portable data loggers were used to monitor the internal conditions within the LEVH between 20/03/2009 and 03/07/2009. Most of temperatures recorded during the period of study are within thermal comfort limits (21°C - 25°C) (Figure 16).

The overall performance of the house, in terms of thermal comfort, was exceptional as indicated by psychrometric chart. Nearly all the input data are within the thermal comfort area as defined by ASHRAE 55 standard (Figure 17).

TAS simulations have proven necessary to investigate the quantity of heating loads required annually for heating space in the LEVH. The heating period for 17 St. Augustine's Road lasts nine months ranging from the end of September (27/09) to the end of April (30/04). There is a small chance that heat may also be used during the early days of May (10/05) (Figure 18).

## 2.4 Summer Performance

The LEVH generally performs well during summertime when most temperatures lie within thermal comfort limits (21°C - 25°C) on each floor. However, there are high overall percentages of temperatures exceeding 25°C, particularly on the 2nd floor, which holds the biggest exposed area to solar gains. In general, all the other floors perform very well in terms of overheating.

Summer overheating is an important issue that ought to be considered carefully in order to prevent the need to increase energy use for mechanical cooling. Various simulations have been conducted to test different options that could make LEVH perform better during summer. Figure 22 summarizes the thermal performance of LEVH according to the refurbishment suggestion, each of which offers different percentages of overheating reduction (Figure 22). Most temperature percentages are within thermal comfort limit for every improvement. Nonetheless, it should be noted that the higher infiltration option might cause cold drafts even during summer albeit it has negligible percentages of overheating.

	Kg CO <sub>2</sub> /year
Predicted Pre-Refurbishment	18,000
Predicted Post-Refurbishment	6,600
Measured/Estimated Post Refurbishment	7,150

Figure 15: Carbon dioxide emissions of the pre-refurbishment and post-refurbishment LEVH at 17 St. Augustine's Road.

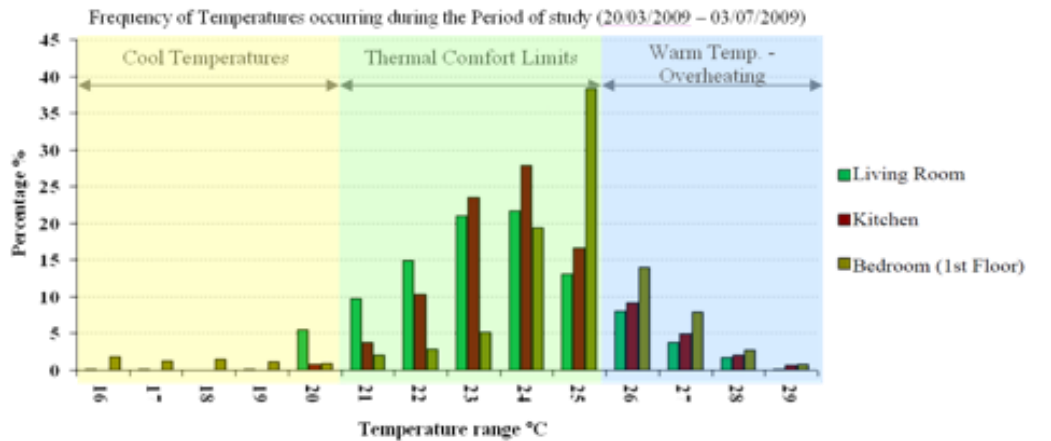


Figure 16: Frequency of temperatures occurring during period of study for each floor.

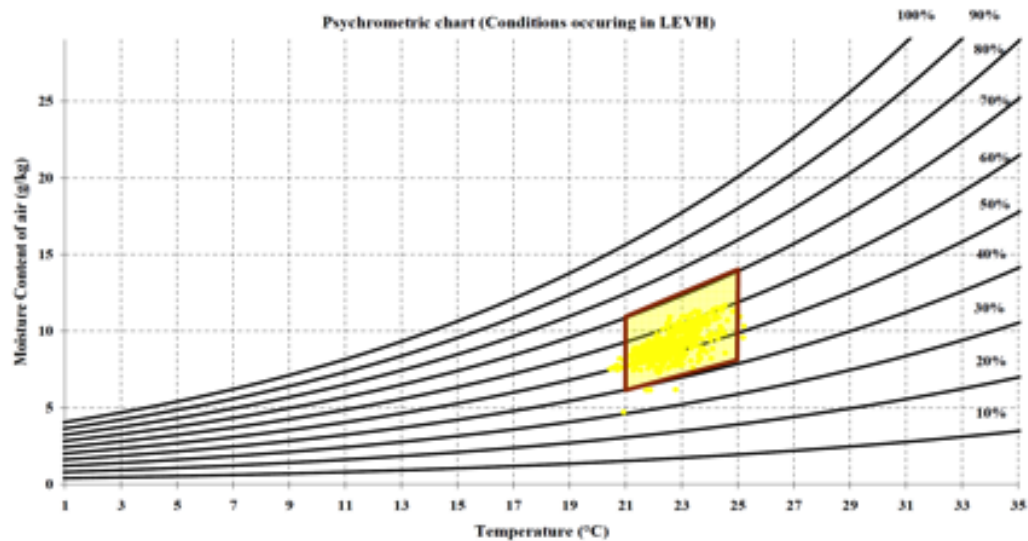


Figure 17: Psychrometric chart for temperatures occurred in LEVH during studied period.

## 2.5 LEVH's performance compared to unrefurbished Victorian dwellings

The LEVH's performance can be better evaluated if it is compared to performance of another two unrefurbished Victorian Properties.

7a and 19 St. Augustine's Road Victorian Houses are semi-detached dwellings with three floors and an attic dating from the 1880s. They consist of solid brick wall construction and single glazed sash windows of wooden frame, but lack wall and loft insulation as well as draft proofing for windows and doors. In both properties, the heating systems are based on old gas boilers with radiators. However, the solid fuel open fireplace found in 19 St. Augustine's Road is rarely operated. Radiators remain in use in all heated spaces during the winter in both homes. Gas boilers with a hot water tank are used for hot water while windows are opened rarely (1h – 2h). All light bulbs in 19 St. Augustine's Road are energy saving, compared to only half of those in 7a. The rating of domestic appliances in both properties is B overall.

Taking into account that the heating system in 7a remains in use for almost 15 hours per day during the particularly cold days of winter, this house seems to perform poorly in comparison to 19 St. Augustine's Road. This uses heating for only 10 hours per day, like the LEVH and achieves cool temperatures closer to thermal comfort limits (21°C - 25°C). Occupants in the LEVH seem to operate their property at comfortable but high temperatures, considering that thermal comfort could also be achievable if temperatures were within the range of 21°C – 23°C (Figure 23). Instead of this, a considerable amount of temperatures (almost 20 %) are above 24°C.

The SAP 2005 spreadsheet was used to estimate carbon emissions, energy demand and fuel costs for each dwelling studied. Each home has a different floor area. Consequently, SAP results are presented per m<sup>2</sup> in order to allow comparison between studied properties. Domestic Carbon Emissions for LEVH have been reduced by 76.25% following refurbishment ( $DER_{\text{original building}} = 73.2 \text{ kg CO}_2/\text{m}^2/\text{year}$ ,  $DER_{\text{after refurbishment}} = 9.6 \text{ kg CO}_2/\text{m}^2/\text{year}$ ), which is close to initial target of Camden Council (reduce CO<sub>2</sub> emissions per 80%). It is interesting to note that 7a St. Augustine's Victorian house has almost the same carbon emissions per m<sup>2</sup> as the pre-refurbishment LEVH. Yet the studied property consists of only one ground floor flat. 19 St. Augustine's Road (a two mid-floors flat) has a lower DER than 7a, but this rating is still high compared to the LEVH. This high value is due to both the location of each flat within the Victorian house and to the lack of insulation and 'dampproofing' on the fabric. As a result, both 7a and 19 St. Augustine's Road have respective DER values is too far above the Target Emissions Rate (TER) set by regulations in 2006 while the LEVH has achieved annual emissions rate below the TER set in 2006 (Figure 24).



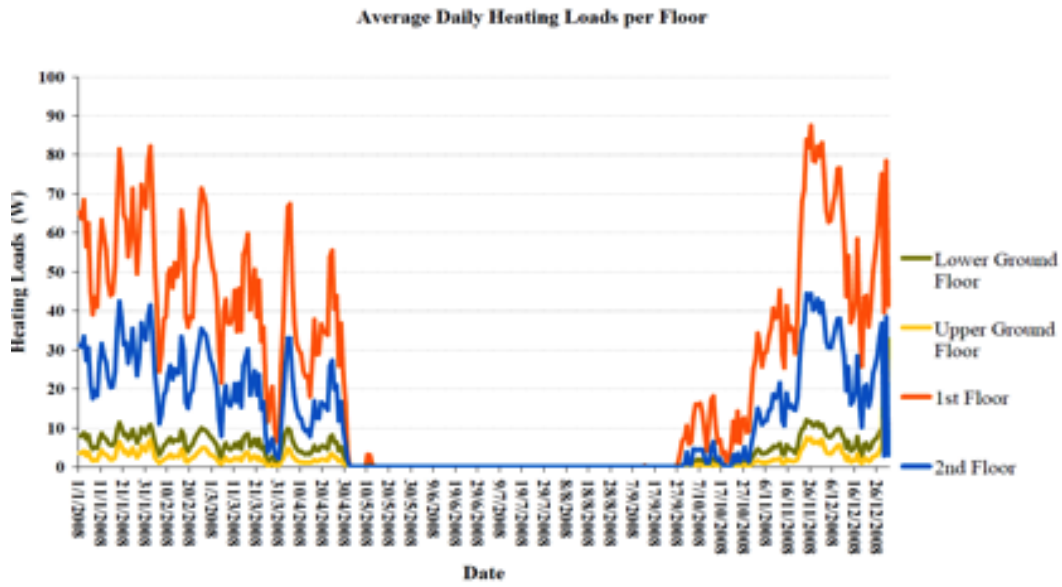


Figure 18 Annual Average Daily Heating Loads for each floor of the LEVH.

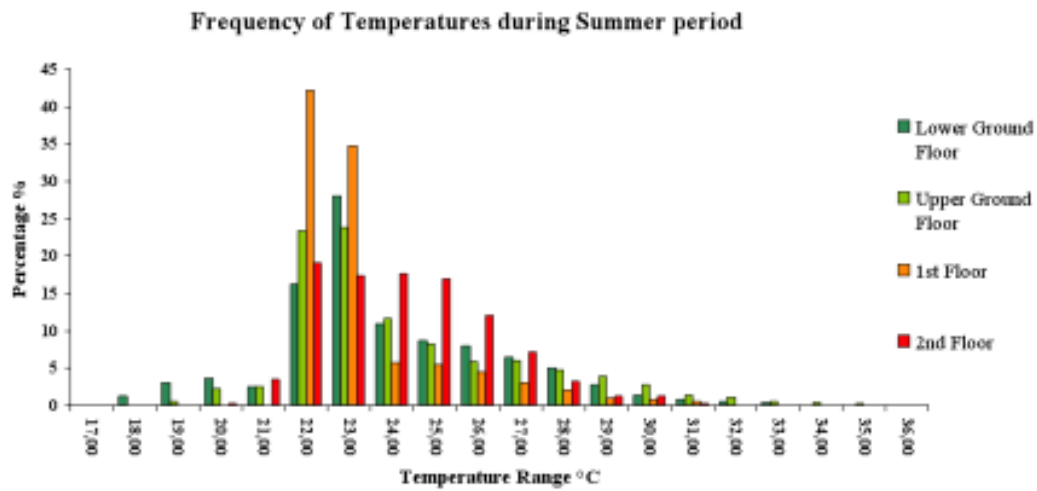


Figure 19: Percentage of temperature occurrence in each floor, during summer period.

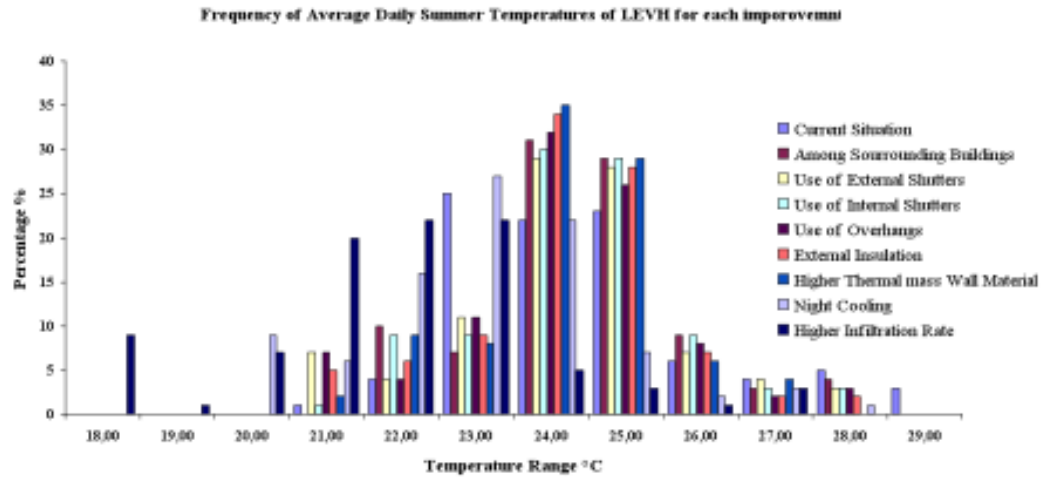


Figure 20: Frequency of Average Daily Summer temperatures in LEVH for each suggested improvement.

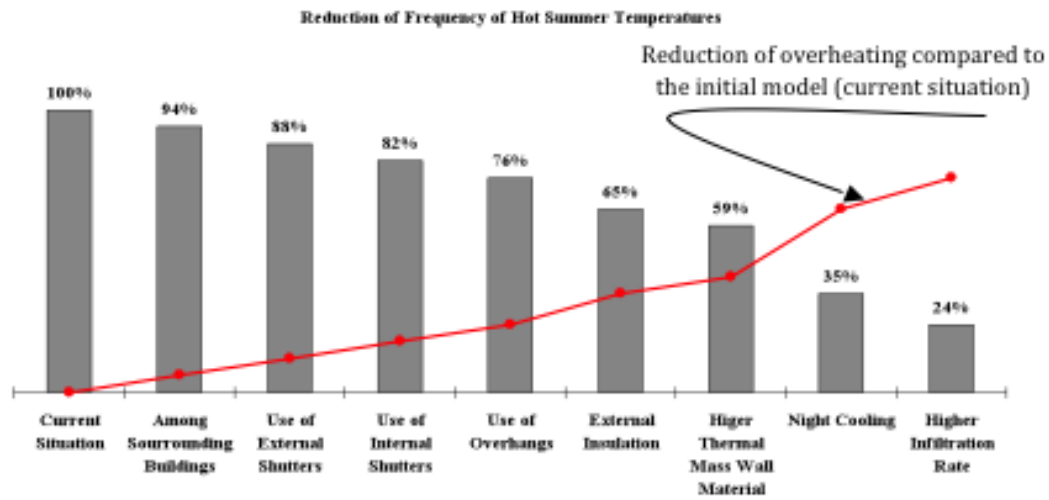


Figure 21: Reduction of overheating percentages under different refurbishment options.

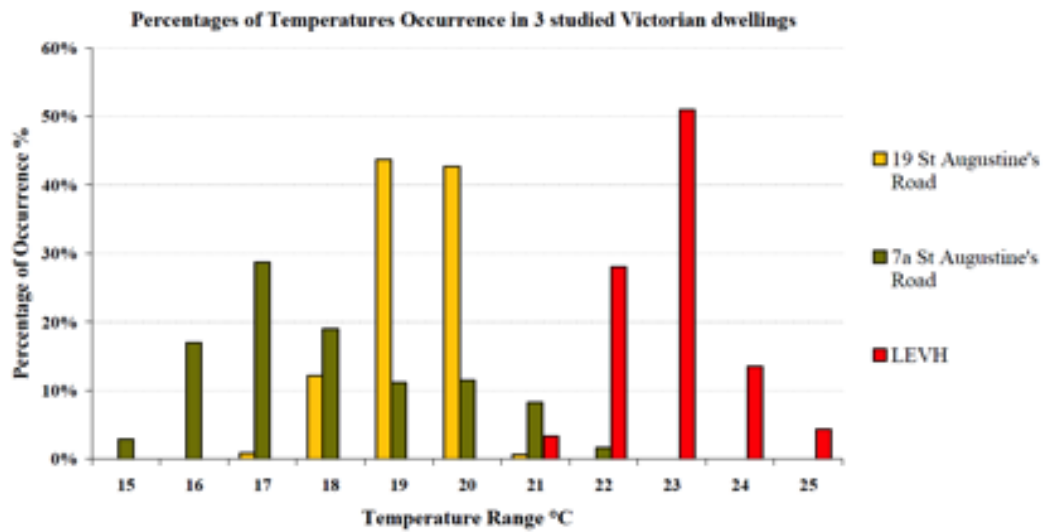


Figure 22: Percentages of Occurrence for 7a, 17 and 19 St. Augustine's' Victorian

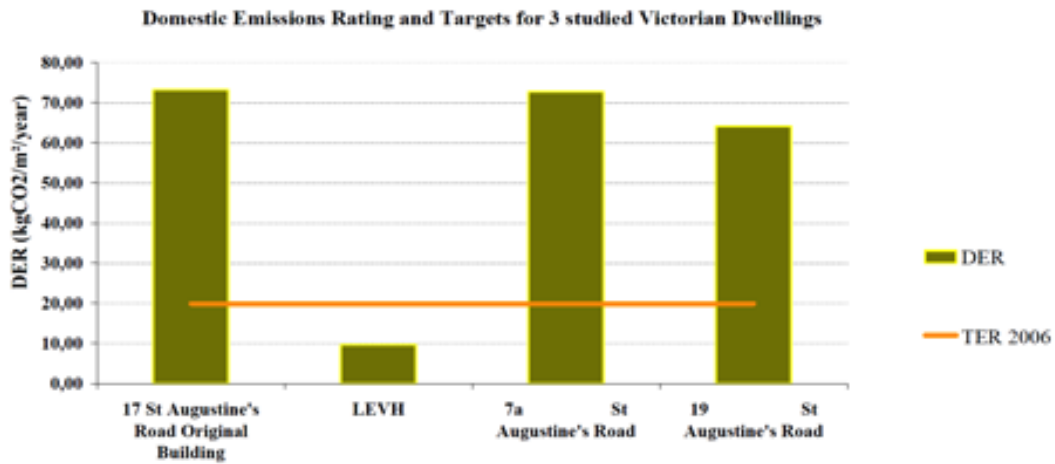


Figure 23: Domestic Emissions Rating in relation to Target Emissions Rating 2006 for 7a, 17 and 19 St. Augustine's' Victorian houses.

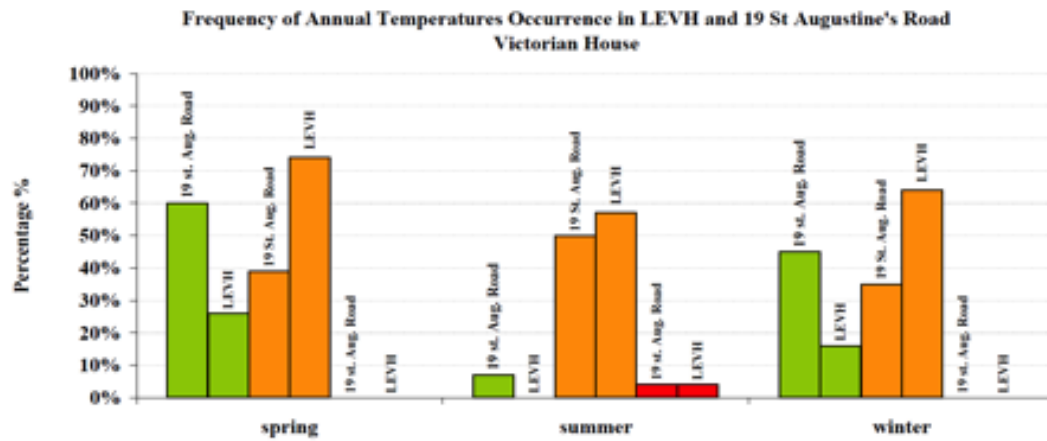


Figure 24: Percentage of annual temperature occurrence in LEVH and 19 St. Augustine's Road Victorian House.

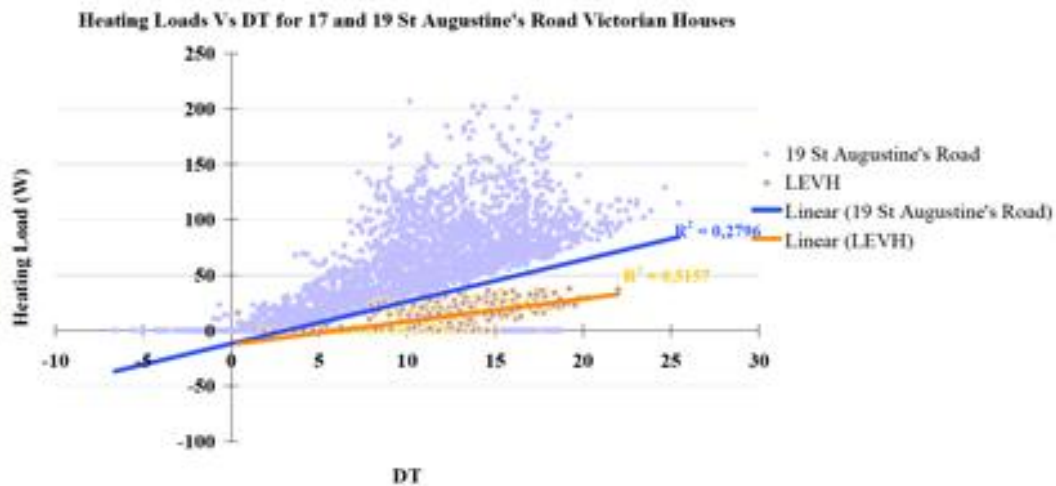


Figure 25: Comparison of heating load demands for LEVH and 19 St. Augustine's Victorian House.

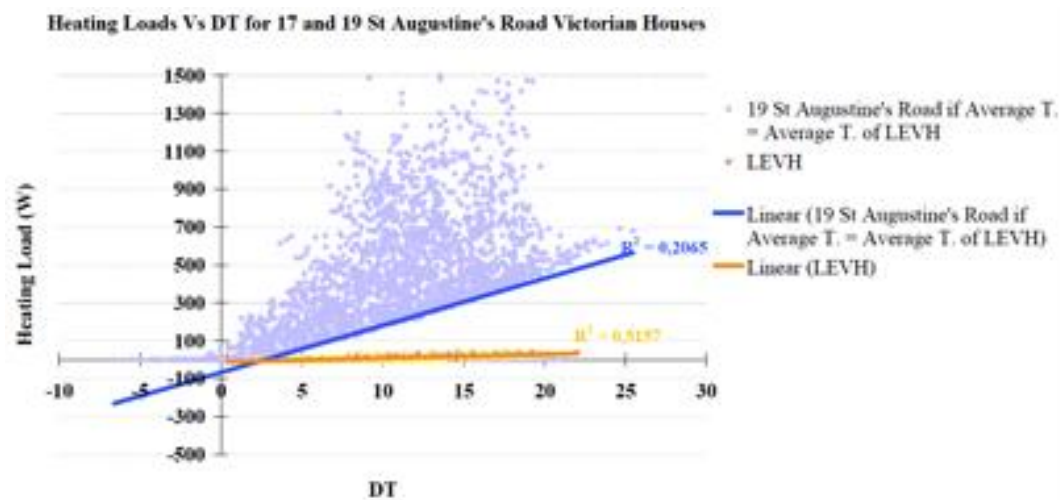


Figure 26: Comparison of heating load demands for LEVH and 19 St. Augustine's Victorian House if 19 St. Aug. Road was operated with the same internal temperatures as LEVH.

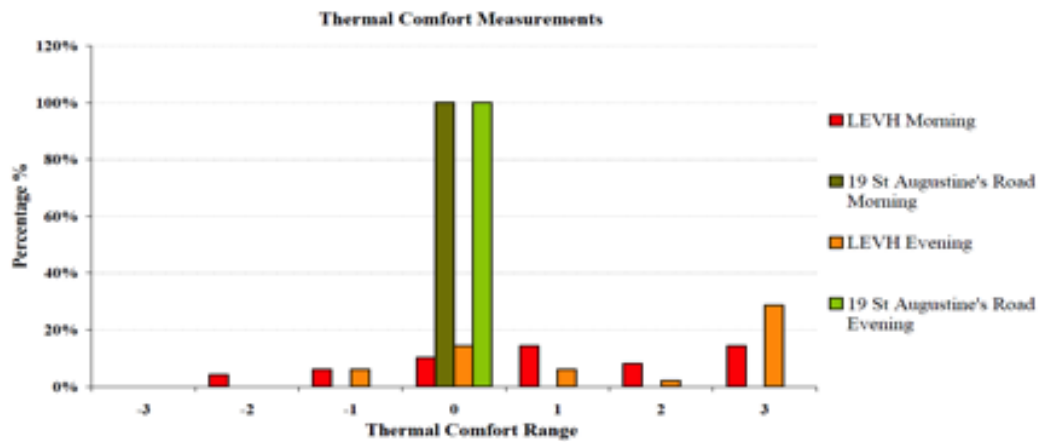


Figure 27: Thermal comfort in LEVH and 19 St. Augustine's Victorian House during a 7-day questionnaire survey.

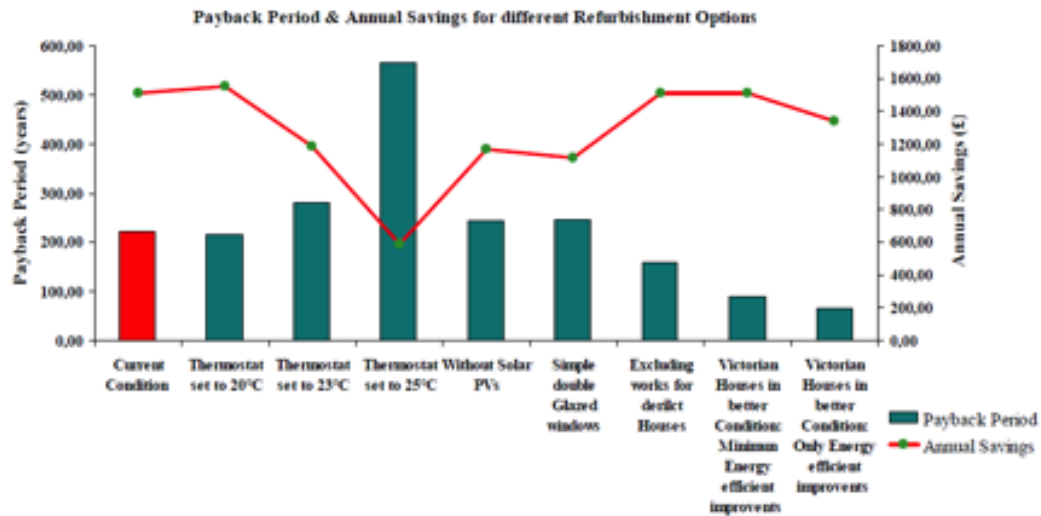


Figure 28: Payback period and annual savings according to different refurbishment options according to data taken from simulations in TAS software in terms of energy consumption.

During spring and winter heating periods, 19 St. Augustine's Road has high percentages of cool daily average temperatures compared to LEVH, and thus lower percentages of temperatures are found within thermal comfort limits. In both houses, warm temperatures do not occur during heating periods (Figure 25). Performance of the refurbished Victorian house (LEVH) is better than original one (19 St. Augustine's Road). However, winter temperatures in the LEVH show that occupants choose to operate their house in increased thermal comfort temperatures. Both dwellings seem to perform similarly during summer. Although, cold drafts in 19 St. Augustine's Road are present due to lack of insulation and more heat losses from fabric during the night when low temperatures are present outside. Both dwellings appear to have the same percentage of overheating. Overheating issues must be studied further in order to suggest adequate further improvements.

In comparison to that of the LEVH, 19 St. Augustine's Road demands a heating load three times greater (Figure 26). On the other hand, if occupants of 19 St. Augustine's Road had chosen to operate their home at the same temperature as 17 St. Augustine's Road, heating loads of the non-refurbished dwelling would have jumped to ten times higher than that of the LEVH (Figure 27).

In conclusion, energy efficient refurbishment of old dwellings provides thermal comfort conditions to occupants while rapidly reducing heating and energy demands. It thus proves to be a beneficial investment for cutting fuel bills while mitigating climate change by reducing carbon emissions.

Finally, the questionnaire survey showed that occupants of 19 St. Augustine's Road felt thermally comfortable during all of the 7-day survey period, while results from the occupants of LEVH models are more varied (Figure 28).

The refurbishment of 17 St. Augustine's Road Victorian house cost approximately £340,000, including costs of major repairs, structural works, and labour. To address whether the occupants manage to reduce their bills for gas and electricity, Camden Council plans to extend the initiative across the borough (Prigg, 2009). Finally, many of those who object to the results demonstrate that refurbishment of Victorian Council House was too expensive in terms of the payback period. (Rupert, 2009) Although refurbishment of the Victorian House was indeed expensive, at £340,000 spent, the investment aimed to save approximately £3,750 annually (assuming UK electric price of £0.08/kWh, and £0.07/kWh for gas). These figures give a simple un-discounted payback period on the order of 90 years. 17 St. Augustine's Road Victorian House was also a dwelling that had remained unoccupied for a long period of time and fallen into a state of disrepair. For this reason, several costly works regarding necessary repairs and removals of damaged elements and waste had to take place together with the energy efficient refurbishment techniques. Consequently, the total cost of refurbishment increased to £340,000, although the cost of energy efficient refurbishment of a correspondent house in better condition could be kept within lower limits.

To further evaluate the cost effectiveness of a refurbishment scheme, it is important to know how long each strategy might take to become cost-effective looking at the life of each aspect and comparing it to its savings throughout. The sum of £334,759 spent on the refurbishment scheme includes work for repairs and other works for derelict homes. Different refurbishment options can be applied to old existing homes according to their current condition and repair requirements to reduce payback period, while improving environmental performance (Figure 29 & 30).

### 3. Conclusion

Climate change is one of the greatest environmental, social and economic threats that our planet currently faces. Since building construction accounts for a significant portion of world energy consumption, upgrading old inefficient buildings so that they may meet principles of bioclimatic design is an effective way to reduce energy use in industrialized countries (Smith, 2005). However, refurbishment schemes should account for both environmental design and conservation of architectural, historic and social values of old existing stock. The refurbished Victorian home at 17 St. Augustine's Road is a representative example of successful energy efficient refurbishment of an old dwelling that resulted in greatly improved environmental performance.

The majority of both measured and simulated temperatures with regard to the properties were found to be within thermal comfort limits, with moderate overheating during a few particularly hot summer days ( $T > 26^{\circ}\text{C}$ ). This latter finding suggests that further investigation may be necessary to determine efficient strategies to mitigate this problem.

By installing a solar PV system, a proportion of the domestic electricity is supplied by a sustainable source thereby significantly reducing gas and electricity consumption and contributing to annual savings. Compared to temperature occurrence percentages in two other un-refurbished Victorian dwellings (7a and 19 St. Augustine's Road), the LEVH performs considerably better in providing thermally comfortable conditions to occupants. Although there are frequently temperatures in the high range of thermal comfort ( $23^{\circ}\text{C} - 25^{\circ}\text{C}$ ), which suggests that tenants are exploiting some of the energy savings to increase the temperature.

SAP calculations have proved that carbon emissions of the LEVH have been reduced by 76.25%, and thus the initial goal to reduce of  $\text{CO}_2$  emissions to between 70% and 80% has been achieved. Comparison of LEVH's carbon emissions and heating fuel consumption with the un-refurbished Victorian property at 19 St. Augustine's Road further illustrates the advantages of the LEVH's huge energy refurbishment scheme. If occupants become more aware of the environmental impact of their energy usage, more sizeable reductions in fuel bills could be achieved.

According to a questionnaire survey, occupants of LEVH appear to be generally satisfied by the thermal performance of the house and the efficiency of the



heating system. Although the annual savings in fuel bills are satisfying, the estimated payback period for LEVH seems to be too long. However, refurbishment options can be different for each existing dwelling and may be formatted to match the needs of construction and the occupants' preferences regarding their annual expenditures on fuel bills while reducing the payback period.

Thus, a prior examination on the situation of old dwellings is suggested in order for adequate refurbishment schemes that fit their needs for energy efficiency to be planned. Occupants ought to be well-informed about sustainable living prior to moving into an energy efficient home in order to achieve maximize the environmental performance of their house and reduce fuel bills. Consequently, further research on refurbishment options related to cost should be conducted in order to reach even more reliable conclusions on practical refurbishment scenarios.

Calculations of annual fuel Costs						
	Energy for Heating	Fuel Cost	Fuel Cost for Heating	Fuel Savings from Energy Produced by PVs	Other Energy/Fuel Requirements Costs	Total Annual Energy Cost
	KWh	p-KWh/year	£/year	£/year	£/year	(1)+(2) £/year
Before Refurbishment	86469,96	1,63	1409,46	0,00	363,10	1772,56
Current Condition	10630,00	1,63(main system)/ 7,12(Secondary system)	229,00	171,50	206,48	263,98
Thermostat set to 20°C	8504,00	1,63(main system)/ 7,12(Secondary system)	183,82	171,50	206,48	218,18
Thermostat set to 23°C	31890,00	1,63(main system)/ 7,12(Secondary system)	549,60	171,50	206,48	584,58
Thermostat set to 25°C	53150,00	1,63(main system)/ 7,12(Secondary system)	1145,00	171,50	206,48	1179,98
Without Solar PVs	10630,00	1,63(main system)/ 7,12(Secondary system)	229,00	0,00	377,98	606,98
Simple double Glazed windows	11161,50	1,63(main system)/ 7,12(Secondary system)	281,67	0,00	377,98	659,65
Excluding works for derelict Houses	10630,00	1,63(main system)/ 7,12(Secondary system)	229,00	171,50	206,48	263,98
Victorian Houses in better Condition: Only Energy efficient improves	10630,00	1,63(main system)/ 7,12(Secondary system)	229,00	0,00	377,98	606,98
Victorian Houses in better Condition: Minimum Energy efficient improves	32790,00	1,63(main system)/ 7,12(Secondary system)	587,60	0,00	377,98	965,58

Figure 29: Calculations of annual fuel cost for LEVH after refurbishment and for different renovation options.

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